Some Real Applications for Negative Materials

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The new near field technologies, Negative Index Materials (NIM) and plasmonics combined with innovation in high dielectric antennas, wireless systems and photonic circuits open the prospect of novel new antennas, integrated circuits, sensors (chemical, biological and individual molecule), medical scanners, displays and imagers which have the potential to outperform conventional technology and open many new commercial opportunities [1]. Rapid developments are now taking place in the development and manufacture of metamaterials for antennas, medical imaging and the management of RF near fields. The interaction of surface plasmons with photonic systems is now being exploited and combined with the maturing photonic crystal technology (PCT) to offer the prospect of near field photonic systems for sensors, displays and communications.

We review the potential impact that these emerging technologies may have on real products and systems. By assessing the performance requirements and the maturity of the technologies we identify the challenges that must be overcome to realise genuine world beating products and speculate on how totally new thinking will be needed to design systems which can exploit the new physics that is emerging.

A number of large technical challenges are ahead in the development of the new technologies. These include reducing loss, increasing isotropy and moving to volume manufacture. Incumbent technologies have shown impressive resilience in meeting new commercial and technological challenges. The massive infrastructure investment and the difficulty in making substantial structural changes in system designs and protocols means that a radical new technology has to show substantial advantage before it can be seriously considered as a contender. We look at how far NIMs amd Plasmonics / Photonic Crystal Technology has to develop to challenge on the real applications stage.

[1] A. J. Holden, "Inside the Wavelength, Electromagnetics in the Near Field, State of the Science Review for DTI Foresight, UK, February 2004, available at: http://www.foresight.gov.uk/

Plasmonic photonic crystals for a new generation of infrared sources and spectroscopic sensors

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Sensors of trace gases are of enormous importance to diverse fields such as environmental protection, household safety, bio-hazardous material identification, meteorology and industrial environments. IR sensors make up a significant part of the gas-sensor instrumentation market, and IR spectroscopy sensors remain the most accurate and reliable because they do not rely on catalytic or electrochemical interactions. Drawbacks of the existing IR gas sensors are their complicated multi-element instrumentation design and their cost.

We propose a new class of IR gas sensors, where the enabling technology is a spectrally tuned plasmonic photonic crystal. Building both the emitting and sensing capabilities on to a single discrete element, Ion Optics' infrared sensorchip brings together a new sensor paradigm to vital commercial applications. We exploit the interaction between surface plasmons at a metal interface with a photonic crystal in silicon to control the spectral response of the surface in reflection, absorption and emission. The unique design uses Si-based thermally isolated suspended bridge structures fabricated using conventional photolithography techniques. The tunable narrow spectral response is defined by the symmetry and periodicity of the metallodielectric photonic crystal. Individual sub-resonances are recognized within this bandwidth. We model their origin through calculations of surface plasmon modes in the metallic grating overlayer. Thin metal layers lead to coupled plasmons at the two metal-dielectric interfaces, that in turn couple to modes in the underlying silicon-air photonic crystal. The effects of lattice type, angle of incidence, etch depth, metal and dielectric properties have been studied. Defects engineered into the photonic crystal lattice provide further improvements for the efficiency of the device and its application to a new generation of infrared sources and spectroscopic sensors.

Photonic crystal sensor with micro flow channels

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Sensor applications of photonic crystals(PCs) have drawn much attention[1][2] because of high sensitivity and suitability for μ-TAS(Total Analysis System)s. Here, we demonstrate a great capability of PCs for Refractive-Index-Sensor(Index-Sensor) and Bio-Sensor applications.

Sensing is performed by measuring the wavelength shift of the photonic-band-edge(PBE) due to the change of refractive-index distribution inside and around the PC caused by the introduction or the adsorption of material. Since the change of transmittance at the PBE is extremely sharp, a high sensitivity is expected.

The device consists of two 10μm-wide waveguides and a 10μm-long two-dimensional PC region of triangular-lattice of air-holes fabricated on an SOI(Silicon On Insulator) wafer with a 200nm-thick SOI-layer. The first PBE in Γ-K direction of TE mode was used for the measurement. To introduce fluid specimen into the PC region, we adopted a technique using micro flow channels made of PDMS(polydimethylsiloxane) [Fig.1].

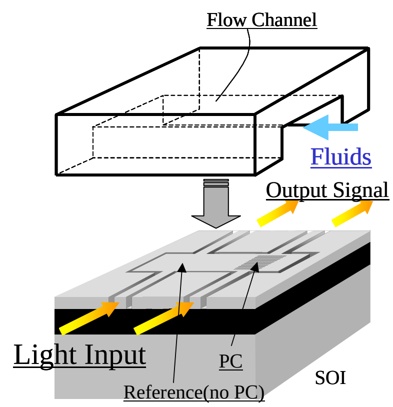

Fig.1 Schematic of device

In the Index-Sensor experiment we measured PBE-shift($\Delta\lambda$)s for water, ethanol and isopropanol(IPA) compared with air[Fig.2]. Considering the two models : Model1(holes filled up with fluid) and Model2(empty holes), even after the introduction of the fluids, holes are not completely filled with each fluid but to the same degree.

For the Bio-Sensor demonstration BSA(Bovine Serum Albumin) labeled with fluorescein was used as analyte protein which is dissolved in PBS(Phosphate Buffered Saline) solution. We have measured $\Delta\lambda \sim$ 0.3nm due to the adsorption of the protein replacing PBS background and $\Delta\lambda \sim$3.3nm for the air background. The experiment and an analytical study lead that the refractive index contrast to the background medium highly influences the sensitivity. Based on the results, we estimated the sensitivity of the PC sensor.

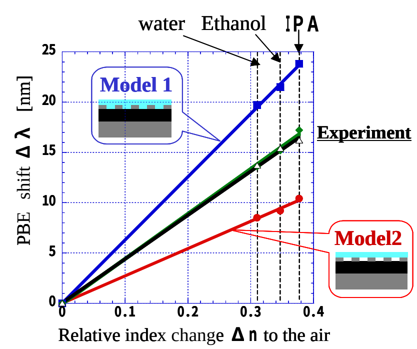

Fig.2 PBE shift for the refractive-index change

In conclusion, by experiment with micro flow-channels, modeling, and quantitative analysis, the first demonstration of PC's possibility for Refractive-Index-Sensor and Bio-Sensor applications has been done.

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[2] E. Chow, et al., Opt. Lett., 29(2004), 1093

Applications of silicon-based photonic crystals

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Silicon is the dominant material in semiconductor industry to date. Novel nanostructuring technologies, such as ICP-plasma etching, photo-electrochemical etching as well as colloidal self-assembly of monodisperse silica spheres, may lead to novel application of silicon in photonics.

Three different areas of applications will be discussed: integrated optical devices, sensors and photovoltaic devices. In the area of integrated optics, the properties SOI ridge waveguides and photonic crystal waveguides will be discussed and the possibility of tuning the optical properties. Concerning sensing, novel design for the gas interaction compartment based on macroporous silicon photonic crystals are presented. Macroporous silicon can be prepared uniformly on 6-inch silicon wafers and the holes can penetrate the whole silicon wafer. This enables gas flow through the holes and optical detection perpendicular to this direction in the plane of the periodicity. Finally, possible applications in the area of third generation solar cells are presented such as spectrum splitting and fluorescence collection. Intriguingly, this is an area has been suggested initially for photonic crystals [1] but has never been followed up.

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Photonic crystals for applications in solar energy conversion

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Nanoparticles play important role in energy conversion since Grätzel and collaborators presented a high efficiency solar cell made from TiO_2 nanoparticles [1]. It has triggered a great effort to find cheap and easy methods [2] for photovoltaic energy conversion that could end up in a market product [3]. However, their performances are not optimum with top efficiency values below 12%.
Photonic crystal concept can provide new solutions to solar energy conversion as has recently been reported by Mallouk et al [4]. Here we report on the fabrication methods to achieve photoelectrochemical cells with inverse opal topology. We will report on the fabrication of inverse opals made from photoactive materials as TiO_2, CeO_2 etc. We are interested to control optical properties of inverse colloidal crystals that would maximise photocarriers generation and, therefore, the device efficiency.

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Sub-wavelength metallo-dielectric photonic crystals#

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The optical properties of a sub-wavelength metallo-dielectric photonic crystal are simulated with a rigorous S-matrix (scattering matrix) theory. The S-matrix approach simulates the reflection and transmission through this structure by solution of eigenmodes within each layer. We calculate the optical properties of a sub-wavelength array of holes in a metal layer on a photonic crystal. These show sharp resonant absorption and equivalently resonant emission modes, at wavelengths close to the lattice spacing. The resonances are characterized by an enormous enhancement of the fields within the sub-wavelength apertures with maxima near the edges of the holes and minima in the interior of the apertures. Simulations for different structural geometries illustrate the nature of the resonant absorption in the sub-wavelength structure and the role of surface plasmon modes at the interfaces.

Simulations provide an understanding of these unusual resonances. Calculations for a thin metal layer with a sub-wavelength array of holes exhibit the well-known extraordinary transmission peaks. Simulated reflection and transmission for photonic crystals (without metal coatings) exhibit guided resonances for out-of-plane propagation which compare well with measurements on silicon photonic crystals. Both sets of resonances combine together to generate the unusual absorption of the metallo-dielectric photonic crystal. Applications to tunable infrared sensors will be discussed by I. Puscasu et al. [1]. Alternative approaches of photonic crystals to wavelength determination will be briefly surveyed.

[I] I. Puscasu et al., abstract submitted to this PECS-VI meeting.

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